Chapter 28

Paleontological Case Study

"Ardi," the *Ardipithecus ramidus* skeleton from Ethiopia

This final case study illustrates the application of human osteology in a deeper paleontological context. Like the previous case studies, this one shows that research in human osteology is a team effort built on the basic skills and techniques of identification, recovery, and analysis.

28.1 Background

Fossil remains of truly early **hominids** are frustratingly rare and incomplete (the zoological family Hominidae — "hominids" — includes *Homo sapiens* as well as all species more closely related to humans than to living chimpanzees and bonobos). Even the relatively intact, uniquely preserved partial skeleton of "Lucy" from 3.2 million years ago represents only a single individual, indeed, so far the smallest *Australopithecus* ever found. There are very few places in Africa, let alone the rest of the world, where a dead organism has a good chance of becoming fossilized. There are even fewer places where these fossilized remains are accessible to the scientists who seek them (White, 2004).

Three of the world's great rift valleys intersect in the Afar Rift of northeastern Ethiopia (Figure 28.1). This large, depressed region is a hot, dry desert inhabited by nomadic pastoralists called the Afar people. Flowing through their desert homeland is the Awash River, draining the Ethiopian highlands (Figure 28.2).

Paleoanthropological research came relatively late to the Afar rift, well after the discoveries of the Leakeys at Olduvai Gorge (in Tanzania) and Lake Turkana (in Kenya). Work in Ethiopia's lower Omo valley (led by Clark Howell and colleagues) was underway when the young French geologist Maurice Taieb became the first to realize the Afar's paleoanthropological potential. Taieb performed geological mapping in this region during the late 1960s, collecting the first fossils along the middle portion the Awash River.

Since Taieb's first explorations, the Afar has become the most important place on earth for the study of human origins and evolution. Discovery of the relatively complete and well-preserved fossil specimen nicknamed "Lucy" by anthropologist Donald Johanson in 1974 first focused global attention here. This and other discoveries at Hadar — the "Lucy" site — led to the recognition of a species of human ancestor known as *Australopithecus afarensis*.

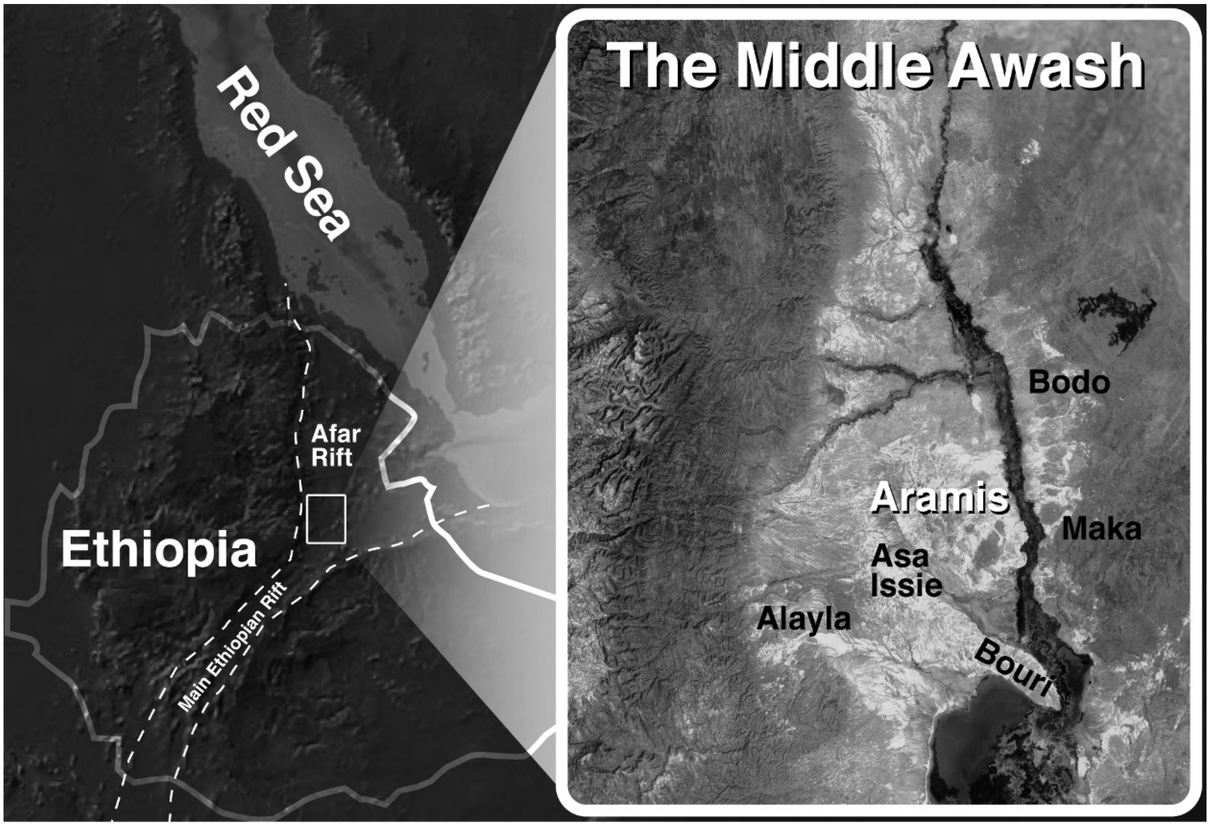

Figure 28.1 **Hominid discoveries**. Map showing the location of Aramis within the Middle Awash study area of Ethiopia. Modified from Gilbert and Asfaw (2008).

When this species was named in the late 1970s its remains came from two sites, Hadar in the Afar, and Laetoli in Tanzania, where Mary Leakey's team had excavated fossilized bones and teeth as well as footprints preserved in hardened volcanic ash. Since then, even more fossils of this species have been found, and deposits in Ethiopia and Kenya have revealed an even earlier chronospecies, *Australopithecus anamensis* (White et al., 2006). The origins of *Australopithecus* have been a key research problem for the 75 years since Dart's initial discovery of this genus in South Africa.

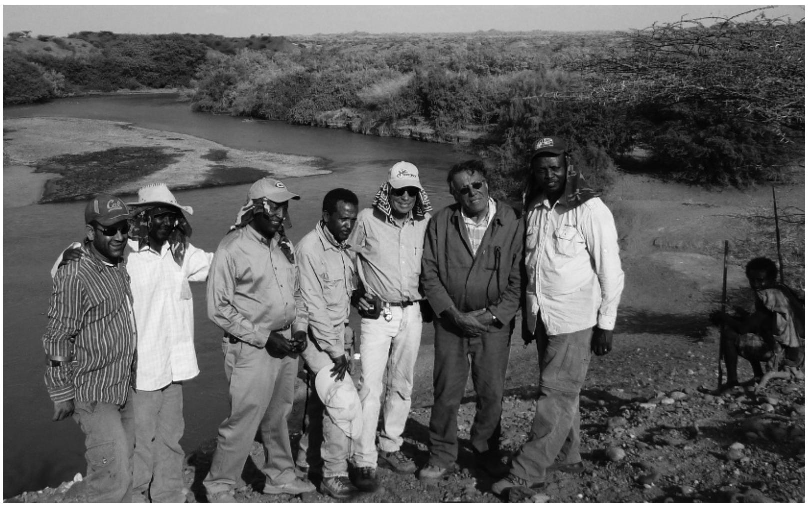

Figure 28.2 **Team leaders**. Middle Awash research team leaders with Maurice Taieb (second from right) on the west bank of the Awash River in 2010. Taieb's pioneering geological work in the 1960s led to the establishment of Ethiopia's Afar depression as one of the most important paleoanthropological repositories on Earth.

Our team, initially led by the late Professor J. Desmond Clark, has been working under Ethiopian government permit since 1981 in a study area designated as the **Middle Awash**, located about 75 km south of the "Lucy" locality (Figure 28.3). Here, beginning in the 1970s, fossil hominid remains from multiple time horizons have been recovered (Shreeve, 2010; White, 2009b, 2010). Among the earliest Middle Awash hominid fossils is a partial skeleton of a young adult female nicknamed "**Ardi**." Its first pieces were discovered in 1994.

Figure 28.3 **Entering the field.** Some paleoanthropological study areas are located in very remote areas. The Middle Awash project team is shown here building a track for the vehicles carrying all of their research and camping equipment into the Afar desert in 2010.

28.2 Finding Fossils

Most of the important fossil remains from open-air sites such as Hadar, Olduvai, Laetoli, Aramis, and Koobi Fora are found as fragments of surface specimens by survey teams walking and crawling eroding outcrops of ancient sediments in search of fossils recently exposed by erosion. There can be literally thousands of fossils at such sites. The identifiable ones are collected and returned to the laboratory for study after their spatial coordinates have been determined to within meter precision by Differential Global Positioning Systems (DGPS; Figure 28.4), and their stratigraphic horizon information recorded by geologists.

Finding the fossils that comprise the very extensive and diverse faunal and floral assemblages for the many localities of the Middle Awash represents a challenge that has led our large international team to devote many years to field research. Each rain brings more erosion to the sediments, exposing more of the buried fossils to the paleontologist. In large collection fields such

Figure 28.4 **Recording positions.** Two vital pieces of information about fossils are their spatial and stratigraphic positions. Here, a differential GPS is being used to determine precise latitude and longitude for the suid (pig) bones marked by the pin flag. The resistant mesa top in the distance is formed by a 5.2 million-year-old basalt. The Aramis localities are much higher in the stratigraphic succession of the Middle Awash, and therefore younger than the suid fossils being collected here from the eroding clays.

as at Aramis, fossils reaching the surface are best recovered as soon as possible because they can be very fragile (Figure 28.5). Organic components within these remains have long since disappeared. The fossilized bones usually fragment below the surface, even before the paleoanthropologist can see them. Once exposed, they scatter more and more widely in successive rainstorms as they weather out of the ancient sediment and tumble downslope, displaced by everything from whirlwinds to foraging goats.

Middle Awash project paleontologists collect fossils ranging in size from pollen grains to seeds, fossil wood, snails, small mammals such as mice, and large ones as big as elephants. Hominid fossils are rare. The Middle Awash has so far yielded more than 20,000 individually catalogued vertebrate fossils. Of these, only about 300 are hominids. It must be emphasized that it is extremely rare for fossil hominid crania or other body parts to be found intact at such open air paleontological sites. Indeed, the term "site" is not an apt description of these occurrences, which are better referred to as "**fossil fields**," in which skeletons are rarer than skulls, skulls are rarer than jaws, and isolated teeth are the most common intact elements found. Taphonomic agents ranging from ancient hyaenas to modern erosion act together to render the fossil record fragmentary.

Compounding the problems associated with erosion, hominids were never common components of total biomass. They had lifetimes much longer than the average mammal's. As a consequence, in any given time interval, relatively few hominid carcasses were available for burial and fossilization. Because of their intelligence and lifestyles, hominids rarely died in swamps or lakes where conditions favored fossilization. Hominids are therefore rare members of fossil assemblages.

Figure 28.5 **Shattered on arrival.** The ancient Aramis silts have a high bentonitic content, so they crack when subjected to repeated wet-dry cycles. By the time the eroding surface reaches fossils, they are sometimes so fragile and fragmented that reconstruction is nearly impossible. Such fossils require immediate application of consolidant and careful extraction.

Given the geological facts and geomorphological settings of such fossil fields, hominids are rarely found *in situ*. Excavations are usually limited to recovering already disturbed and scattered remains of fossils found by paleontologists surveying the surfaces of eroding sedimentary units. The human osteologist working under such conditions must therefore be able to identify small, scattered, and often highly fragmentary skeletal and dental elements. Indeed, were it not for the osteological skills of the surveyors, many fossils such as the famous *Homo erectus* Turkana Boy (specimen KNM WT-15000) from northern Kenya would remain unidentified and unrecovered. If the survey osteologist dismisses a small hominid fragment as an unidentifiable scrap of bone in the field, it may be many years before anyone returns to the area. Field identification is truly the key to success.

The concept of a **search image** is important in this kind of surface survey. It is obvious that a paleontologist wishing to recover the jaw of a shrew-sized animal remains spends a great deal of time on his or her knees, closely scrutinizing the surface of the ground for tiny bones and teeth. The paleontologist searching for fossil elephant remains, in contrast, can walk quickly across the outcrops, scanning much larger areas of the surface for much larger remains. The paleontologist searching specifically for hominid remains should carry an intermediate search image, whether the application is forensic, archaeological, or paleontological. Isolated hominid teeth are usually discernible only from a bending or kneeling stance on the outcrop, whereas a distal femur can be spotted from standing position.

28.3 The Geography, Geology, and Geochronology of Aramis

Today the Awash River supports a wide, green ribbon of vegetation that winds through the otherwise parched desert landscape of the Afar. Each of the small tributary drainages that flow into the modern Awash River bears an Afar name. The Middle Awash project uses these names to identify paleontological and archeological collection areas within which localities are then designated (Gilbert and Asfaw, 2008). Except when the stream infrequently floods due to local rains, the **Aramis** tributary is a dry wadi (dry streambed) within a small catchment whose walls carve into the upper part of a 300-meter-deep sedimentary succession. The overall stack of geological layers in the immediate area ranges in age from 5.5 to 3.4 million years (Renne et al, 1999).

The ancient strata exposed by recent and ongoing erosion in the Aramis area were originally deposited horizontally, in a layer-cake fashion. Today the beds are tilted about five degrees toward the east due to continuing tectonic activity, and faults slicing through the beds are abundant. Each sediment layer in the depository contains clues to the past. Layers of black basalt show that molten lava flowed out to cover a floodplain. In the area's stratigraphic succession, coarse-grained sandy beds are evidence of ancient rivers and lake margins. Lignite beds indicate swamps. Ancient shallow lakes revealed by thinly laminated sediments contain abundant fossilized fish and crocodiles.

The desolate badlands of the Aramis area today bear no resemblance to the many habitats available to the Pliocene creatures who roamed this place millions of years ago. Indeed, in their efforts to probe the past, paleoanthropologists have come to understand that it is sometimes best to ignore the modern lakes, rivers, streams, and mountains that they see today. This is because most of these modern features making up today's geography had not even formed at the time of deposition of the fossiliferous sediments.

Not only were the ancient landscapes very different from those that we see today, but the deposition on these landscapes took place at higher elevations, long before the Afar floor had been dropped to its present low elevation by massive tectonic movements associated with rift formation. Our paleoanthropological challenge at Aramis was to locate and recover fossils and contextual data that would allow a detailed understanding of what this part of the world was like thousands of generations before "Lucy" was even born.

Determining the age of the Aramis sediments was a challenge when we first visited in 1981. The animal fossils found eroding from them were somewhat similar but generally less evolved

than those found at Hadar, to the north (Hadar had already been dated to between 3 and 4 million years ago). Fortunately, intensified work in 1992 allowed Middle Awash project scientists to locate multiple volcanic horizons at Aramis. These could be directly dated by the Argon-Argon radioisotopic technique, and the calculated ages cross-checked via paleomagnetism and biochronology.

Two of the volcanic horizons centered in the long sedimentary succession at Aramis were traced across the eroding landscape, dated, and named. "Gàala" means "camel" in the Afar language (abbreviated GATC for "Gàala tuff complex); "Daam Aatu" means "baboon" (abbreviated DABT for "Daam Aatu basaltic tuff"). These provided virtually indistinguishable dates of 4.4 million years (Figure 28.6). The dated volcanic strata were separated by a few meters of sediments deposited on a broad, flat floodplain. Very large assemblages of invertebrate and vertebrate fossils were embedded in the silty sediments sandwiched between these tuffs, all of them well-calibrated to a period over a million years older than "Lucy."

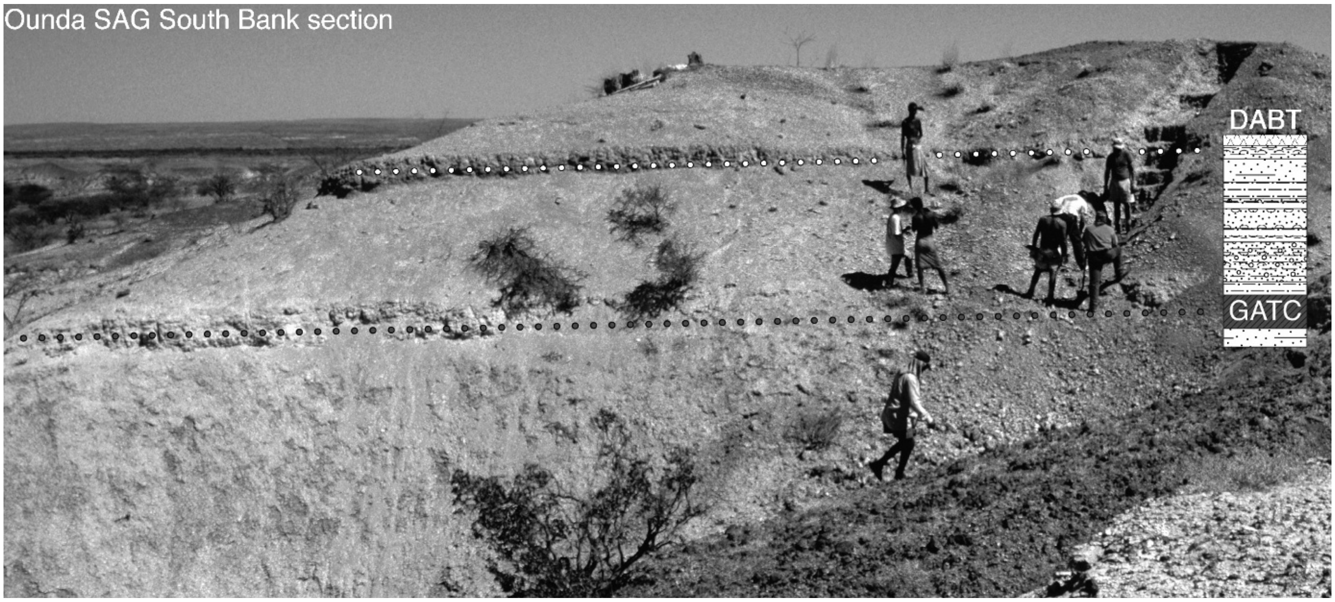

Figure 28.6 **Bracketing the fossils.** The narrow stratigraphic window sandwiched between two volcanic ash horizons at Aramis (each dated by the Argon/Argon radioisotopic method to 4.4 million years old) contained the "Ardi" skeleton and the thousands of other fossils associated with it.

28.4 Discovering "Ardi"

As they began collection of surface fossils at Aramis in 1992, Middle Awash team members were familiar with the challenge of finding and recognizing the few, usually broken hominid bones and teeth scattered on sedimentary outcrops. The Aramis outcrops were then unusually rich in vertebrate and invertebrate fossils, with abundant bones and teeth representing dozens of ancient species. Most of these fossils, however, were highly fragmentary due to the active hyaena population in the area when this was a wooded floodplain during the geologically brief interval between the two volcanic eruptions 4.4 million years ago.

We were initially impressed by abundant fossil wood at Aramis. Also abundant were leaf-eating monkeys called colobines, and spiral-horned antelope called tragelaphines. The first hominid specimen found was an upper third molar found and identified by Gen Suwa, a Japanese paleontologist. During the first two field seasons our team recovered more parts, belonging to several

additional individuals of this new hominid species. We recovered more isolated teeth, associated dentitions, a child's jaw, a basicranium, and a few limb bones. We published our initial research results in the journal *Nature* in late September, 1994. A little more than a month later, we were back on the Aramis outcrops to continue controlled, cautious collecting. Not only are the eroding slopes at Aramis soft and the fossils fragile, the sediments between the volcanic ashes are often steep, littered with carbonate rubble that makes good hiding places for scorpions and vipers.

Due to the fact that so much of the fauna had been anciently broken into very small pieces, and our realization that there were thousands of such pieces on these outcrops, the project had developed the technique of "crawling," (Figure 28.7) to collect all available fossil material at Aramis. Crawls are generally upslope in direction, conducted by teams of between 5 and 15 collectors who

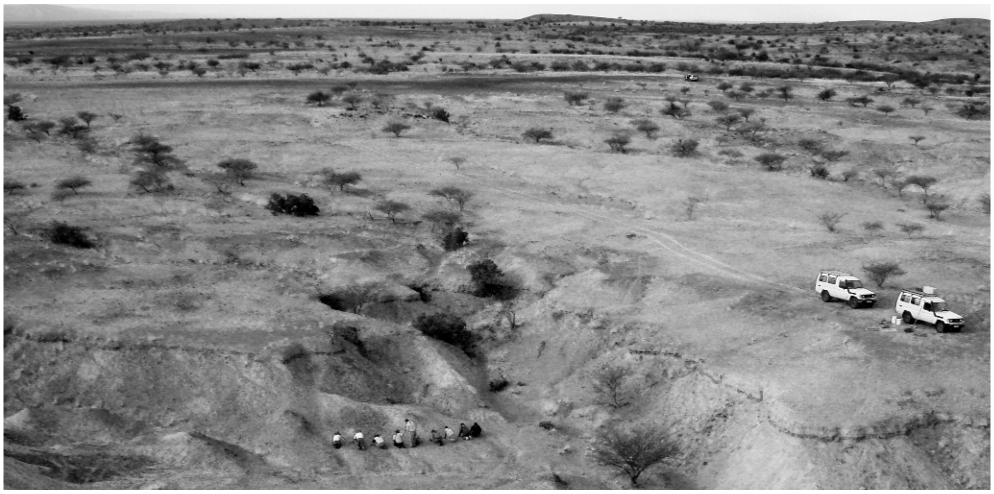

Figure 28.7 **Helicopter** (*top*) **and ground-based** (*below*) **views of fossil collection**. Crawling the surface of the Aramis sediments below the DABT tuff horizon dated to 4.4 million years. The team crawls shoulder-to-shoulder, picking up every fossil fragment within a designated segment of outcrop. The most highly skilled osteologist, the crew chief, is responsible for evaluating the collections as they are compiled. If a particularly valuable fossil is found, crawling ceases, and sieving ensues to recover scattered and, sometimes, *in situ* fragments.

crawl the surface on hands and knees, shoulder to shoulder, collecting all fossilized biological materials between a prescribed pair of taut nylon cords. The Aramis exposures were repeatedly collected with this technique between 1993 and 2005.

The overall Aramis GATC-DABT fauna was so thoroughly fragmented by **taphonomic** causes (see Chapter 20) that we had little expectation of finding more than a few bones belonging to any one mammalian individual — let alone a hominid. It was therefore not surprising that the "Ardi" partial skeleton discovery began with just such a small piece, found late in the afternoon of November 11th, 1994, by then-graduate student Yohannes Haile-Selassie (who had used earlier editions of *Human Osteology* to help learn and then teach bone identification and field techniques). Just 54 meters north of the boulder left by our team ten months earlier (to mark a juvenile's scattered teeth), he found the base and then the distal end of a second metacarpal belonging to an adult hominid (Figure 28.8).

After he and the other "crawlers" gently retreated in their own footprints (to avoid crushing any other potential fragments), a "no-go" perimeter was established around the fossil so that others would not tread on any additional pieces that we suspected might be lying nearby because of the recent breaks on the metacarpal shaft. It is very important to control the passage of people across a new discovery site because even well meaning efforts have the potential to push fragile fossils into the soft surface, or even crush them underfoot (see Chapter 15).

In a situation such as this, it is very important to establish the distribution of all pieces of the hominid fossil. We do this with pin flags set at the undisturbed location of each piece. This procedure is important because it provides critical clues about the position in which the fossil was originally buried, and thereby provides a guide to the recovery operation that must inevitably follow.

Figure 28.8 **First fragments**. Second metacarpal fragments were the first element portions found at the ARA-VP-6/500 discovery site in November of 1994.

The most opportune time to find a fossil is just after the first part of it has been exposed by erosion. Unfortunately, the paleontologist usually arrives later than this. As discussed above, many fossils have already entirely weathered out of their original deposit by the time they are discovered. However, by carefully assessing the geomorphology and lithostratigraphy of the site, the surface scatter, and matrix on the specimen, it is often possible to identify the original stratum that contained the fossil, and the spot from which it most likely came.

Pinpointing the *in situ* resting place of a fossil can be much like placer mining for a gold vein. The original spot from which fossils have eroded can be converged upon by looking at the concentration and patterning of fossil fragments—and by taking local topography into account. Many fossils found during paleontological surface prospection have lain on the erosional surface for years. In the case of the "Ardi" discovery, we had a real exception to that rule; we had been lucky to find this fossil while parts of the skeleton were still embedded below the surface, protected from erosion. But we didn't know that in the beginning; we were just collecting loose fossils on the surface.

Indeed, our initial encounter had suggested that this was simply an isolated, broken metacarpal. No other fragments were visible on the surface, and darkness was falling. Since no rain was imminent, it was judged safe to return to camp after marking the discovery spot and delineating the catchment area in which additional recovery efforts were needed. The individual initially represented by the metacarpal fragments was given the specimen number designation "ARA-VP-6/500," specifying it as the five-hundredth specimen from ARAmis Vertebrate Paleontological Locality number 6.

28.5 Recovering "Ardi"

During the next week we repeatedly returned to Aramis Locality 6 to carefully sweep the loose sediment around the initial metacarpal discovery point. These loose sediments were sieved through 1.5mm screen (Figure 28.9). Sieving produced additional hominid phalanges, and as we plotted the position of these pieces, we began to identify the likely source of the bones, a small hill just upslope from the spot where the first metacarpal fragments had been found. As we brushed

Figure 28.9 **Screening for shattered fragments**. Loose sediments surrounding the original surface find are systematically sieved. Establishing the distribution of surface fossils is a key to identifying the original position of the bones, and a necessary step in determining whether additional fossils may be *in situ*.

and scraped the loose sediment from the outcrop, we exposed a hominid phalanx *in situ*, followed by a femur shaft and nearly complete tibia (Figure 28.10). Subsequent excavation at a rate of ~20 vertical mm/day across ~3 square meters during 1994 and 1995 revealed >100 additional *in situ* hominid fragments, including probable hand and foot sesamoids. All were fragile and many were crushed; even some molars had been exploded by calcite crystal growth (Figure 28.11).

There were many questions that arose as we slowly and carefully uncovered the fossils. How many individuals were represented? How much of the skeleton(s) might eventually be found? What kind of a hominid was this? The task at hand, however, was to focus on the controlled exposure and extraction of whatever fossils were still embedded in the silty clay. A skeleton of this antiquity had never been found, so it was obviously scientifically important, as well as representing Ethiopian and world heritage. It was a very heavy responsibility to ensure that everything was recovered without any damage to the uniquely ancient fossils. The activities required for successful extraction of all the pieces lasted over three successive field seasons (Figures 28.12 and 28.13).

The bony remains were off-white in color and very poorly fossilized. Smaller elements (hand and foot bones and teeth) were mostly undistorted, but all the larger limb bones were variably crushed. In the excavation, the fossils were so soft that they would crumble when touched. Each was rescued after exposure by dental pick, bamboo, and/or porcupine quill probe. Exposure was followed by *in situ* consolidation.

As the excavation proceeded, we were forced to dampen the encasing sediment in order to prevent desiccation cracking that would further disintegrate the fossils during exposure and removal. Each of the skeletal elements and/or fragments required multiple coats of consolidant, followed by extraction of the sediment block containing the bone inside, protected and stabilized with encasing plaster and/or aluminum foil jackets (Figure 28.14). Additional consolidant was applied before the fossils were transported to the laboratory at the National Museum of Ethiopia in Addis Ababa.

Figure 28.11 **Fracture and distortion**. Even the teeth were affected by post-depositional processes. In the case of this molar crown, calcite crystals grew between cracks in the crown to displace the mesial margin from the rest of the tooth. This matrix had to be removed, the enamel fragments isolated, cleaned, and then glued together properly after all internal anatomy had been measured and recorded.

Figure 28.10 **The tibia**. The "Ardi" tibia was encountered *in situ* by sweeping, and required immediate application of consolidant (hardener) to solidify it prior to extraction.

Figure 28.12 **The excavation**. The "Ardi" discovery site before, during, and after excavation. Field operations of three years established the perimeter of the scattered pieces that the team was able to recover via excavation.

Figure 28.13 **Jacketing a limb bone**. Only the upper surfaces of larger bones were exposed before the specimen was pedestaled, and a plaster jacket was formed with medical bandages in order to protect and stabilize the fossil prior to removal to the laboratory.

Figure 28.14 **Slow, careful excavation proceeds**. Excavation of the site at the end of the 1994 field season. The sediment had to be kept damp in order to prevent dessication cracking, and slow, painstaking excavation was required to avoid damage to the bones entombed in the ancient silts.

Pieces were assigned number suffixes based on recovery order. Back-dirt was weathered in place and re-sieved each season. The 1995 field season yielded facial fragments and a few other elements in northern and eastern extensions of the initial excavation. Further excavation in 1996 exposed no additional remains but established a wide perimeter around the polygonal distribution of hominid skeletal elements.

Each fragment's position, axial orientation, and dip were logged relative to a datum (strata here dip east at ~4° to 5°) (Figure 28.15). The polygon representing the outer perimeter and vertical extent of the hominid fragment constellation (based on each bone's center point) was ultimately demarcated by a carapace of limestone blocks cemented after excavation with concrete, then further protected by a superimposed pile of boulders to permanently mark the discovery site and spatial distribution, per local Afar mortuary custom.

Figure 28.15 **Plotting the distribution**. The bones were tightly clustered spatially and stratigraphically. Here, the base of each yellow pin flag represents the center point of each fossil already extracted from the excavation. The beds here have been tilted to the east (away from the photographer) by faulting.

The distribution of bones and local microstratigraphy indicated that they had come to rest in a shallow swale on the ancient floodplain. There was no evidence of weathering or mammalian chewing identified on ARA-VP-6/500. Bony elements were completely disarticulated and lacked anatomical association. Many larger elements showed pre-fossilization fragmentation, orientation, and scatter suggestive of trampling (Figure 28.16).

The skull was particularly affected, its facial elements and teeth found widely scattered across the excavated area. Bioturbation tilted some phalanges and metacarpals at high dip angles (Figure 28.17). A few postcrania of a large *Aquila* (eagle) and other birds were recovered during excavation, as were a few micromammals. No large mammal remains besides isolated cercopithecid teeth and shaft splinters from a medium-to-large mammal limb bone were associated. Evidently, the carcass had decomposed close to where it ended up on the ancient floodplain.

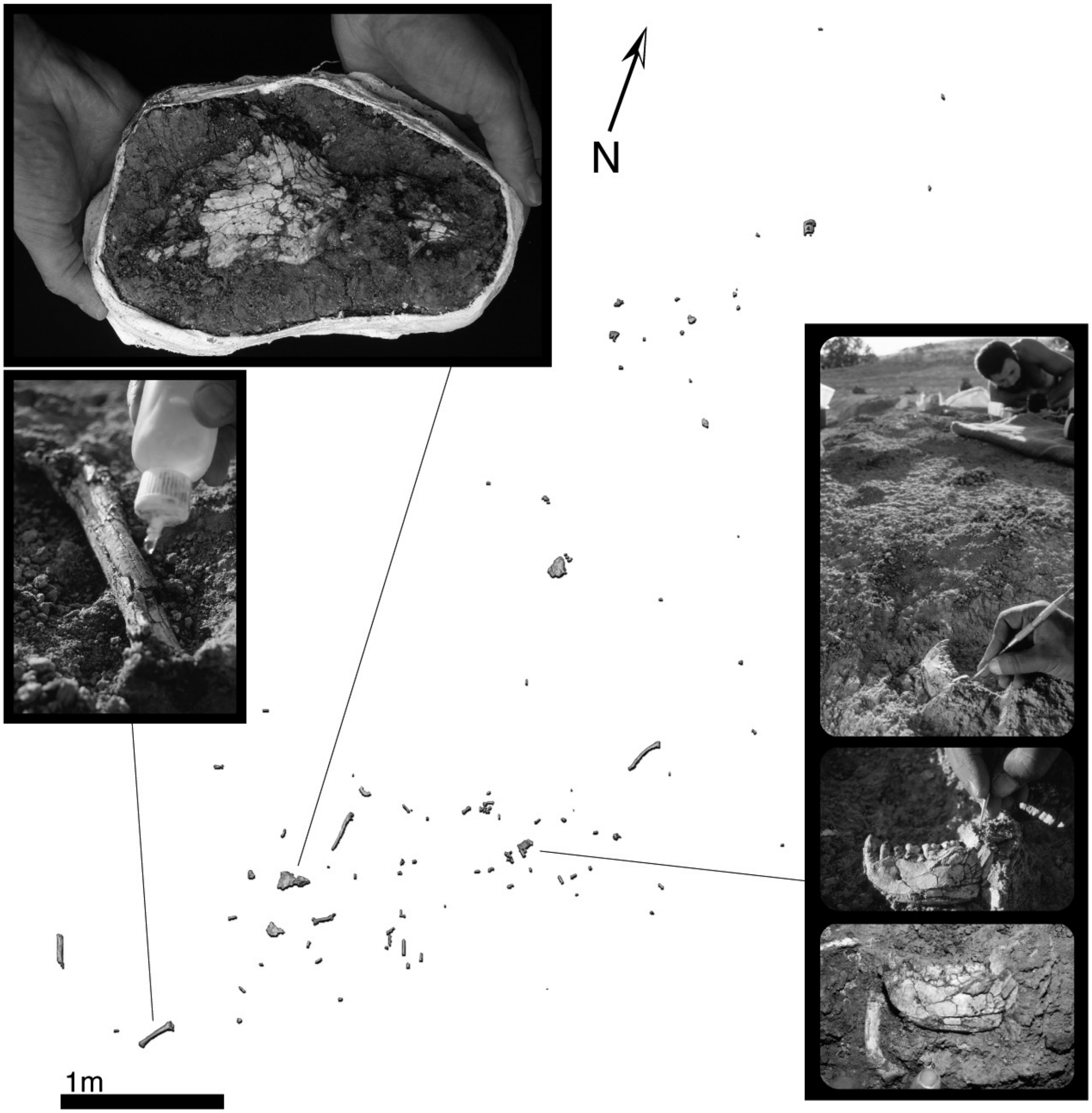

Figure 28.16 **Distribution of elements**. The plan view of the *in situ* skeletal element distribution at the ARA-VP-6/500 hominid excavation.

Figure 28.17 **An *in situ* hand phalanx**. Individual fossils had already begun to disintegrate below the surface because of the expanding and contracting silty clays they had been buried in. Careful excavation was required to expose the major dimensions of each specimen, and each was lifted individually after liberal application of consolidant.

28.6 Restoring "Ardi"

Removing the skeletal remains to the laboratory was the only way to ensure the time and equipment necessary for their safe extraction from the crumbling matrix that still held them (Figures 28.18 and 28.19). Exposure and consolidation of the soft, crushed fossils were both accomplished under a binocular microscope.

Acetone was applied with brushes and hypodermic needles to re-soften and remove small patches of consolidant-hardened encasing matrix. Microsurgery under a binocular microscope at the interface between softened matrix and bone proceeded millimeter-by-submillimeter. Each cleaned surface was re-hardened with consolidant after exposure. This process took several years. The freed specimens remain fragile and soft, but radiographic accessibility is excellent. Most restoration and correction for distortion were accomplished with plaster replicas or micro–CT digital data in order to safeguard and preserve the fragile and precious original fossils in their discovery state.

Figure 28.18 **Plaster jacket**. The lateral surface of the left os coxae of the skeleton is seen here in the plaster jacket. In the laboratory the matrix was removed millimeter-by-millimeter.

Figure 28.19 **First season's yield**. At the end of the first field season, many individual elements of the skeleton had been recovered, and are shown here within their plaster jackets, ready for transport to the National Museum of Ethiopia for further preparation.

28.7 Documenting "Ardi"

The National Museum of Ethiopia employs many techniques to make permanent records of its fossil heritage. Prior to molding, each specimen is photographed and videotaped from many angles. Because of the fragility of the "Ardi" specimen, its parts were subjected to micro-computed tomography (micro CT). This scanning provided internal images with which the analytical team could access and study such things as cortical thickness of the various bones (Figure 28.20). Furthermore, the non-invasive, internal views of the bones allowed their distortion to be accurately assessed and compensated for. Finally, by segmenting the various broken fragments, digital restorations were possible to achieve for crushed and distorted elements such as the mandible and cranium.

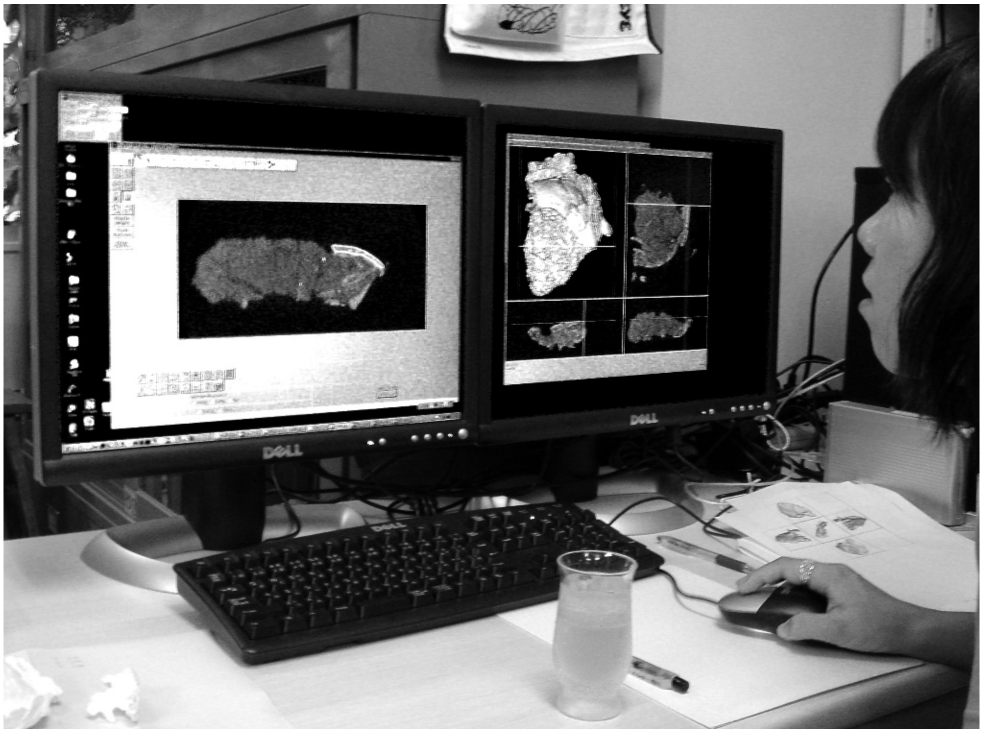

Figure 28.20 **Digital segmentation of the crushed cranium**. Once the bones had been freed from matrix, they were subjected to micro-CT scanning, which allowed accurate restoration of the original piece, in this case, the crushed cranium.

Silicon rubber molds were prepared after the specimens were cleaned and stabilized (Figure 28.21; see Chapter 16 for details of these procedures). The first "perfect" casts (dental plaster for dimensional stability) produced from these molds were designated as record casts and locked in a protected location in the unlikely event that the original fossils are ever lost or destroyed.

28.8 Studying "Ardi"

One of the first questions asked by the Aramis field recovery team about the set of fossils recovered at the "metacarpal" site was whether we were excavating remains of a single individual. The answer would not be available until well after excavation was over, the fossils cleaned and restored, and a full Minimum Number of Individuals assessment completed (Chapter 16).

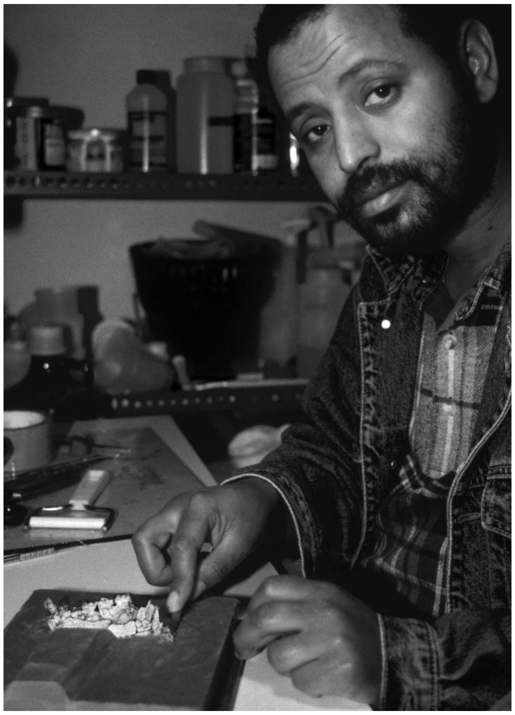

Figure 28.21 **Molding the mandible**. The lower jaw of "Ardi" being prepared for molding with silicon rubber. The two-part mold will make multiple, highly accurate physical copies of the specimen for study and display around the world. Not even the highest resolution micro-CT scanner can render stereolithographic casts with the detail captured by the silicon rubber.

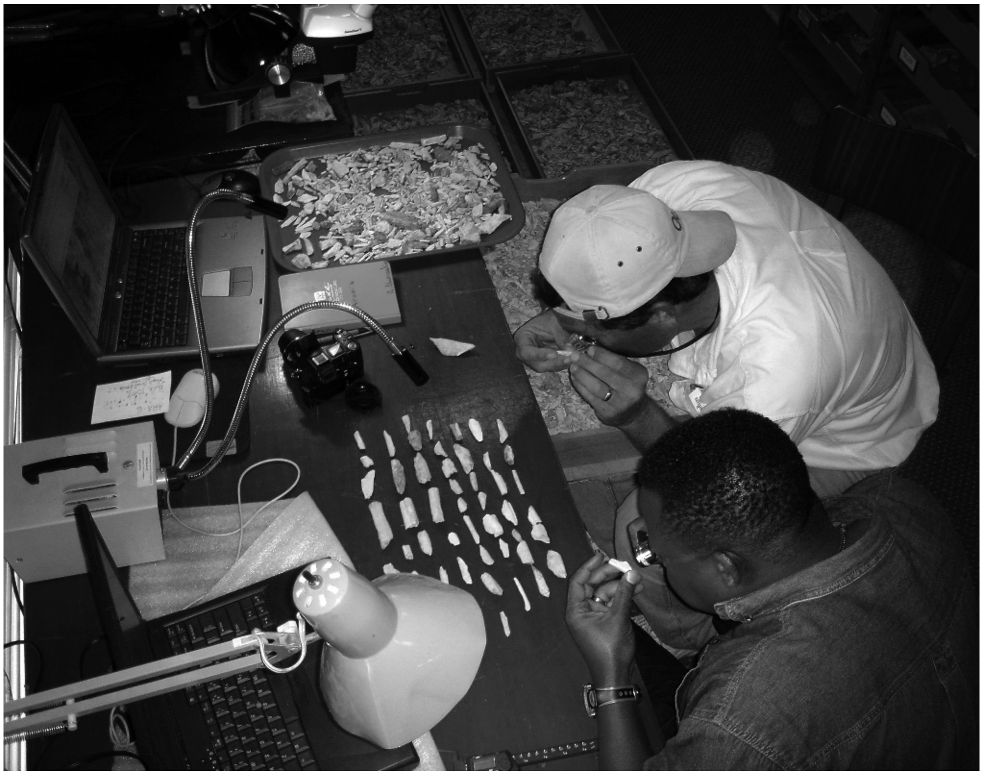

Figure 28.22 **Specialists at work.** Dozens of scientists from many disciplines were involved with the work on the Aramis fossils. Here, thousands of shaft fragments, mostly from large ungulates found in the same stratigraphic interval as the "Ardi" skeleton, are being identified, and their surfaces analyzed during a taphonomic analysis.

No surface or *in situ* fragments of the ARA-VP-6/500 specimen represented duplicated anatomical elements. Only 10% of the 136 total pieces were surface recoveries at the excavation site; all other pieces were excavated *in situ*. Preservation was identical across the entire recovered set of remains. There was no evidence of different maturational ages among the 136 pieces, and many of them conjoined.

Given the close stratigraphic and spatial association, and given no evidence of any other individual from the carefully excavated spatio-stratigraphic envelope, it was evident that the parts of the ARA-VP-6/500 specimen represented a partial disarticulated skeleton of a single individual. Estimation of the "percentage" representation of a skeleton is not very meaningful in a case like this, but the most important parts of any early hominid skeleton are the skull, teeth, arms, hands, pelvis, legs, and feet. All these were recovered for this individual, judged to be adult due to the fully erupted and wearing third molars, and the complete epiphyseal fusion of all elements.

The cause of death was indeterminate. The specimen was judged to be female on the basis of an extensive analysis of the dentition (the cranial and pelvic anatomy of such an early hominid cannot be assessed by techniques used to sex modern humans). The only pathology revealed by close examination was a partially healed osteolytic lesion of the left proximal ray 5 pedal phalanx (ARA-VP-6/500-044) indicating local infection.

28.9 Publishing "Ardi"

As with any modern multidisciplinary research into human origins, the Middle Awash project includes personnel from many different countries working together on myriad aspects of the study area's prehistory (Figure 28.22). The Aramis hominid discoveries (a MNI of 36 *Ardipithecus* individuals were represented in the collections) were accompanied by massive data sets that took a very large team 17 years of laboratory and field work to compile and assess.

Because of the abundance of information, each group of plants and animals had to be recovered through fieldwork, and then analyzed in Ethiopia and many other laboratories throughout the world. Because of "Ardi's" completeness and particularly poor fossilization, great care had to be taken in preparing the fossils for handling, and then molding, photographing, reconstructing, and conducting comparisons with other fossil and modern ape and hominid species.

Many specialized techniques and instruments were used in these studies, ranging from mass spectrometers (to measure the age of the rocks, and composition of isotopes of the tooth enamel and soil carbonates), to micro-CT scanners (to restore and study the inner and outer anatomy of the bones and teeth), to scanning electron microscopes (to study structure and surface details of bone and teeth). Obtaining and processing just the *Ardipithecus* CT scans took thousands of hours. Many more were spent gathering and analyzing comparative modern ape and human materials.

A total of 47 different scientists representing 10 countries and many different research areas of paleontology and geology worked together to author the 11 scientific papers ultimately published in the journal *Science* in October of 2009. These papers covered a variety of different subjects ranging from geology (WoldeGabriel et al., 2009) to "Ardi"s preferred habitat (a woodland; White et al., 2009; Louchart et al., 2009) to her postcranial (Lovejoy et al., 2009a–d), cranial (Suwa et al., 2009) and dental anatomy (Suwa et al., 2009). As one of the earliest hominid skeletons ever found (Figure 28.23), she will be curated as a national treasure in Ethiopia, where she will be studied by generations of scholars to follow us.

It is hoped that by applying the fundamentals of osteology outlined in this textbook, many more such discoveries and interpretations of human and prehuman skeletal remains will follow, helping to illuminate many aspects of the recent and distant pasts.

Figure 28.23 **The "Ardi" partial skeleton.**